Adapting to climate: a case study on riverine flood risks in the Netherlands

Tol, R.S.J.; van der Grijp, N.M.; Olsthoorn, A.A.; van der Werff, P.E.

published in
Risk Analysis
2003

DOI (link to publisher)
10.1111/1539-6924.00338

document version
Publisher's PDF, also known as Version of record

Risk Analysis, Vol. 23, No. 3, 2003

Adapting to Climate: A Case Study on Riverine Flood Risks in the Netherlands

Richard S. J. Tol,[1,2,3,*] Nicolien van der Grijp,[2] Alexander A. Olsthoorn,[2] and Peter E. van der Werff[2]

Climate change may well lead to an increased risk of river floods in the Netherlands. However, the impacts of changes in water management on river floods are larger, either enhancing or reducing flood risks. Therefore, the abilities of water-management authorities to learn that climate and river flows are changing, and to recognize and act upon the implications, are of crucial importance. At the same time, water-management authorities respond to other trends, such as the democratization of decision making, which alter their ability to react to climate change. These complex interactions are illustrated with changes in river flood risk management for the Rhine and the Meuse in the Netherlands over the last 50 years. A scenario study is used to seek insight into the question of whether current water-management institutions and their likely successors are capable of dealing with plausible future flood risks. The scenarios show that new and major infrastructure is needed to keep flood risks at their current level. Such a structural solution to future flood risks is feasible, but requires considerable political will and institutional reform, both for planning and implementation. It is unlikely that reform will be fast enough or the will strong enough.

KEY WORDS: Adaptation; climate change; flood risks; institutions; Lower Rhine

1. INTRODUCTION

Studies of the impact of climate change often ignore adaptation,[4] and studies that include adaptation often follow first-order approaches under a *ceteris paribus* assumption.(2) This may well be inappropriate, because people's and systems' relations to climate tend to change due to many factors (technology, wealth, land use), the majority of which are not related to climate. So, to better understand reactions to climate change, we must study the institutions that channel people's perceptions and intentions into actual responses to expectations of climate change.

This raises questions such as: Do water managers realize that the climate is changing? Do they recognize the implications for their tasks and objectives? If so, are they able to react timely and adequately? What constitute institutional barriers to implement certain proposed flood risk mitigation schemes? And what, given current societal trends, are the prospects for adapting institutions to find better and feasible responses to climate change?

In this article, we focus on water management in the Netherlands, in particular management of flood risks posed by the large rivers (Meuse and Rhine). In this context, the questions of awareness of climate change and its implications are not particularly

1 Centre for Marine and Climate Research, Hamburg University, Hamburg, Germany.
2 Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands.
3 Center for Integrated Study of the Human Dimensions of Global Change, Carnegie Mellon University, Pittsburgh, PA.
* Address correspondence to Richard S. J. Tol, ZMK, Troplowitzstrasse 7, 22529 Hamburg, Germany.

4 Adaptation is the knowing and unknowing response of actors and systems to climate change, either in anticipation of or reaction to, so as to mitigate the negative impacts of climate change and maximize its positive impacts, whether successful or not.(1)

0272-4332/03/1200-0575$22.00/1

interesting, as everyone who has something to do with Dutch water management knows about climate change. We therefore largely restrict ourselves to the conflict between what should be done about increasing flood risks and what can be done in the current and expected future institutional context. The central question in this article is whether Dutch water-management authorities will be able to cope with a substantial increase in riverine flood risk. As our answer is no, this automatically leads us to propose institutional reform. Current decision making is too vulnerable to being hijacked by special and local interests, both in the planning and in the implementation phase. At the same time, local knowledge and interests are disregarded. The current separation of water management and land-use planning policies also creates unnecessary problems for adequate flood management.

The article has three building blocks. One is an analysis of trends in water-management institutions in the Netherlands.[3] The second building block is an engineering study of future flood risks.[4] The third building block consists of two case studies. The first is on the implementation of a current flood management project: the *Maaswerken*.[5] The second case study is on the public acceptability of a future flood management project: the *Rijn op Termijn*.[6] In this article, we bring the three elements together to study potential adaptation to flood risks in the Netherlands. Miller *et al.*[7] and Cohen *et al.*[8] also emphasize the importance of institutional arrangements for water-management issues in the United States and for flood management of the Columbia River, respectively. Kelly and Adger[9] similarly stress the social context of adaptation. Strzepek *et al.*[10] go a step further and build scenarios of future institutions and context as well, a more or less similar approach as the one taken here.

The article follows this route. We sketch the current developments in water management against the background of societal trends, and extrapolate these to the future (Section 2). Section 3 lays out solutions to current (*Maaswerken*) and anticipated (*Rijn op Termijn*) flood risks. The institutional responses to these initiatives are discussed in Section 4. Section 5 concludes.

2. FLOOD RISK MANAGEMENT AND TRENDS IN WATER MANAGEMENT

The Netherlands is densely populated with prosperous and well-educated people. Decisions are typically made through consensus. The country is formed by the deltas of the rivers Scheldt (a rain-fed river originating in southern Belgium), Meuse (a rain-fed river originating in northern France), and Rhine (a glacier- and rain-fed river originating in Switzerland). The Scheldt River connects Antwerp Harbor to the North Sea. The Rhine is the largest of the three rivers. Just after passing the Dutch-German border, it splits into three major branches (the IJssel, the Lek, and the Waal) and a number of smaller branches. The Waal branch connects Rotterdam Harbor to the German industrial heartland. The country is flat. Centuries of subsidence have left most of the country below mean sea and river level. Dikes and dunes are supposed to protect the country from floods from both sea and river. Centuries of floods have left the people rather nervous and inventive about flood risk management. Water flows are regulated through an elaborate system of canals, sluices, pumps, and so on. Dutch civil engineers are amongst the best in the world when it comes to engineering water works.

Flood risk management is only one part of water management, although it has top priority. Under current national law, flood risk, inland navigation, fisheries, leisure, rivers as a fresh water resource, and nature conservation must be managed in an integrated way. Recently, under the expectation of increasing flood risks, the water-management community advocated a more important position for water management in national spatial planning in the Netherlands. The possibilities for dealing with very high river discharges should become one of the guiding principles for national spatial planning.

Reflecting these multiple interests of rivers, water management is carried out by a complex array of authorities. An overview of the main players and their main responsibilities can be found in References 3, 11–14. Van der Grijp and Olsthoorn[3] identify four major trends in water management over the last 50 years. These trends may well continue to change institutions in the same direction for the next 50 years.

The first trend is *internationalization*, or the geographical extension of policy from the local scale to the watershed. Water-management policy, traditionally a matter of local and regional authorities, was first nationalized by Louis Napoleon, viceroy for his brother Bonaparte (see References 15 and 16 for a more extensive review of the history of flood management in the Netherlands). The responsibility of the central government for water issues was reconfirmed in the Constitution of 1848, and strengthened in the Constitution of 1983. Operational responsibility for flood safety rests with the water boards. The flood of 1953 led to a reorganization of the water boards. There were over 2,500 semi-professional water boards in 1950. There are less than 50 fully professional ones now.[11] Geographical upscaling of institutions continues at an international level. The 1986 Sandoz incident[5] gave teeth to the International Rhine Committee, though initially only to chew on water-quality and pollution issues. Since the floods of 1995, mostly in Germany, its mandate has included flood control.[3] The Helsinki Convention provided a framework for treaties on the Meuse.[17] The new EU Water Directive is likely to reinforce the trend of internationalization of river water management.

The second trend is *integration*. Water has many roles, and water management serves many purposes. These include drinking water, irrigation water, navigation, recreation, nature preservation, fisheries, and cooling water. Problems may arise because of floods, droughts, and contamination. All these roles and the associated management goals come together in one system, and pretending that interactions do not exist may be seriously misleading or counterproductive. Yet, different aspects of water are often still managed by different entities with different, occasionally conflicting, interests. Over the years, and particularly in the last decade, integration of water issues has been pushed by the central government.[18] However, operational reality lags behind.[19] It should be noted that, currently, integration more or less stops where the water ends. Land-use planning and water management remain largely separated, although there is considerable mutual consultation.[20]

The third trend is *democratization*. Engineers, bureaucrats, and politicians have less to say about water management than they used to. More stakeholders get increasingly involved. This is marked by the gradual extension of voting rights in water boards from large landowners to all inhabitants (completed in 1994).[19,21] More importantly, elaborate impact assessments of proposed projects are now required by law, media attention to planned infrastructure can be enormous, and public hearings are extensive.[3] Although this increases the democratic nature of decision making and thereby the quality of planning and implementation, it may also increase its costs and slow down the process considerably.

Note that in reaction to the (near) floods of 1995, the *Deltaplan Grote Rivieren* (Delta Plan for Large Rivers) was introduced. The accompanying law accelerates and streamlines decision-making procedures, partially reversing the democratization trend. This law applies also to infrastructure other than flood-safety-related investments.[22]

The fourth trend is *ecologicalization*. Water management used to be decided on a narrow economic and engineering calculus, and used to be biased by typical civil engineering thinking. The upsurge of the environmental movement in the 1970s, reinforcing the older movement for protecting landscape and cultural heritage, changed this. Notably, during that time, plans to impolder the IJssel Lake and the Waddensea were abandoned, and plans to close the Eastern Scheldt Estuary were changed, all in favour of nature preservation.[23] The thoughts behind these isolated decisions are now pervasive. Civil engineering has given way to ecological engineering. Rivers are no longer just transport channels and a resource of fresh water, but important recreation areas and part of the "ecological main structure." The current round of dike reinforcements is supposed to be the last one. After 2000, flood risk management should make use of natural dynamics, rather than concrete and steel.[12]

These trends both constrain and enable future management options. Together, they determine what options are feasible, and which one is likely to be adopted. Reactions to climate change should be placed against this background.

3. A RADICAL PLAN TO COPE WITH CLIMATE CHANGE

The implications of climate change may be quite severe for river deltas such as the Netherlands. The majority of general circulation models (GCMs) project winter precipitation to increase in the Rhine River basin.[6] This would increase the risk of river floods.[26–28][7] Earlier snowmelt in the Alps could further enhance river floods. Sea level rise would slow down the outflow of water. In the Netherlands, the impact of climate change on water resources and flood risks is clearly recognized. The works of the

5 A factory spilled large quantities of poisonous chemicals during a fire.

6 That is, GCMs that look at the effect of greenhouse gas emissions generally project the northern half of Europe to get wetter. GCMs that also include sulphate aerosols occasionally project a drying of northern Europe.[24] However, acidification policies in Europe rapidly decrease sulphur emissions.[25]

7 Note that sizeable rivers such as the Rhine react to above-average rainfall for an extended period (at least a month) over the whole watershed.[29,30] GCMs are more reliable for this type of floods than for flash floods and floods of small rivers, and the Rhine catchment is sizeable to be resolved in a GCM.

Table I. Annual Average Damage (in Million Guilder per Year) Due to River Floods in the Limburg Meuse Valley[a]

Policy Intervention	1995	2050[b]
Do nothing	9.9	21.8
Embankments	0.7	1.5
Nature development	0.6–3.3	1.4–7.3
Deepen summer bed[c]	3.5	7.4

[a]Average damage is estimated using a hydrological model of the Meuse, coupled to a GIS database of the stock at risk from flooding. Modeled flood damage is calibrated to the actual flood damage of 1995 (without policy intervention). Input comes from a stochastic weather generator, calibrated to current climate and a scenario of future climate.
[b]Winter temperatures 2°C higher than today, winter precipitation up 10%.
[c]The summer bed is that part of the riverbed that is permanently flooded. The winter bed is only flooded in winter and early spring.
Source: Schuurman.(32)

Committee Boertien is one example, but there are more.(3)

This committee studied flood risk management along the river Meuse. The Meuse is a medium-sized rain-fed river originating in the north of France, traversing Belgium and the Netherlands to mouth in the North Sea. The Limburg Meuse Valley is unique for the Netherlands[8] because it is hilly and there are no dikes because the soil is such that water would seep underneath the dike (if there were one). Severe floods in 1993 led the government to install Committee Boertien (officially: *Commissie Watersnood Maas*) with the assignment to assess what could be done to avoid flood damages in the future.(31) The findings of this committee with respect to the benefits of possible options to reduce flood risks with and without climate change (Table I) are interesting.

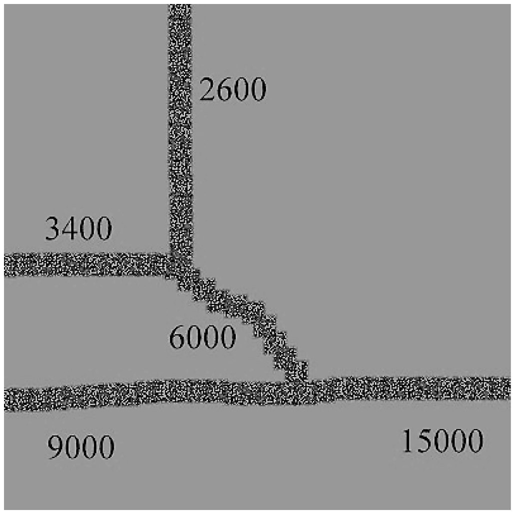
Table I shows the estimated annual average flood damage for various management scenarios. The Committee Boertien included robustness to climate change in their study, using a temperature and precipitation scenario for the year 2050 that is arbitrary but still well within the set of possibilities. Scenarios like this should be viewed as a sensitivity analysis rather than a forecast. A relatively modest change in climate (a 2°C temperature increase and a 10% precipitation increase in winter in 2050) would more than double the average annual damage. Medium-sized European rivers typically respond in this way.(33,34) But, under the studied management interventions (see Table I), average damage would be kept below the 1995 damage. However, the studied management interventions would reduce average damage by a factor of 3–16. Thus, in the Limburg Meuse Valley, the effect of management is much stronger than the effect of climate. That is, the impact of climate change is "noise" compared to the "signal" that management potentially effectuates. This is true for many impacts of climate change.(35)

The situation is completely different, however, for flood risks along the river Rhine. The flood risks posed by the Rhine and its branches are much larger than the flood risks of the Scheldt and the Meuse. This has to do with the large discharge of the Rhine, and the fact that the areas adjacent to the river are polders. Most polders are below mean river level, so if water gets in, it needs to be pumped out, which takes a long time. If a dike breaks, fast-flowing water would cause a lot of damage. The traditional first response to expectations of increased risk would be to raise dikes. However, this approach is widely rejected as not sustainable.

Unfortunately, no one has found a neat solution so far to the climate-change-induced increase of flood risks. A default solution would be to continue current and past practice of solving problems as they emerge (that is, after some harm is done), and picking a solution that does not upset the delicate balance of interests. This has proven to be quasi-successful, although problems were often shifted in place or time rather than solved.(15,16) It is doubtful whether this strategy will be of great help in dealing with climate change due to the scale of the problem and the state of the current water-management system. Works to improve the weakest dikes were accelerated in 1995. No definite plans have been decided upon for after 2000. Proposals, which focus on increasing the retention and recreational value of the flood plains, tweak the water-discharge system, but do not substantially alter it.

The alternative would be a radical redesign of the delta of the water-management system. In 1998, the research institute Delft Hydraulics(4) produced a blueprint *Rijn op Termijn*. This plan is not painless, but it could take away a number of current problems and prevent a number of future ones. The core element of the blueprint is to redistribute the water flow over the three branches of the Rhine, that is, the Waal, the Lek, and the IJssel (see Fig. 1). The Waal, which discharges most of the water, is the major shipping route from Rotterdam to Germany and back. The Lek and the IJssel are less important.

[8] Although more common in the rest of the world. Limburg is the southern-most province of the Netherlands, squeezed in between Belgium and Germany. The Meuse is on the Dutch-Belgian border, the Limburg Meuse Valley is shared by the two countries.



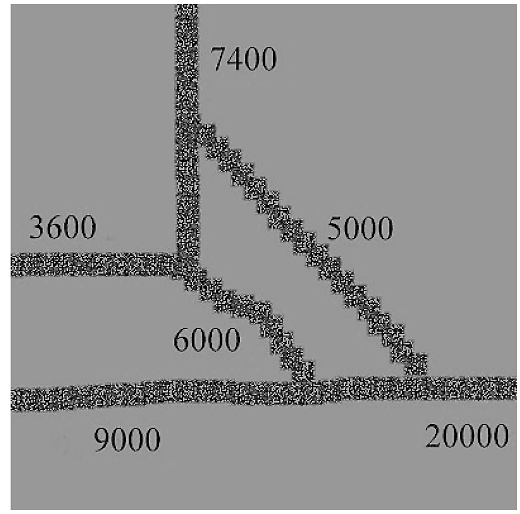


Fig. 1. Current (left panel) and proposed future (right panel) distribution of the Rhine's peak flow over its branches. The 5,000 m^3/s branch is additional and only used in times of high water. It involves digging a new canal but largely relies on an earlier branch of the river.[4]

Climate change is likely to increase the peak flow. In the study by Delft Hydraulics, the design peak discharge is assumed to increase from 15,000 m^3/s to 20,000 m^3/s. This is an arbitrary but not implausible scenario. The design peak discharge is the maximum river flow—as measured at Lobith where the Rhine enters the Netherlands—that occurs without causing severe floods downstream. The design peak discharge constitutes the first element of the guidelines for flood protection. The second element of flood protection is the acceptable risk of dike overtopping. This risk is set by Parliament, upon advice of a committee of wise men.[37] The current risk is 1/1,250 year, that is, river dikes and other water works should be built such that they fail less than once every 1,250 years. The tolerated risk is so low because the would-be damage is so high. Should a dike break or be overtopped, a large polder would fill with fast-streaming water. It would take months to get the water out. The acceptable risk does not comprise a valuation of personal risks.

Confronted with a higher peak flow, one could do several things. First, water-management authorities could hope that the Germans would solve the problem, and store excess water somewhere in a reservoir. The current discussion in Germany suggests that this is an unlikely scenario, for several reasons. One such is that water management is the terrain of the *Bundeslaender* rather than the federal government, which hampers any structural solution to the flood problems along the Rhine.[38] Another reason is that building (temporary) reservoirs is not the preferred option from a German perspective.[4]

Second, one could accept more frequent floods. This is not an option in the Netherlands. The 1995 evacuation of 1 in 60 of the population is still fresh in people's minds, and not to be repeated. Recent attempts to introduce flood risk insurance failed for lack of interest by insurers and reinsures.[2,35,39,40] The Netherlands is becoming a "zero-risk" society, that is, the tolerance of involuntary risks is low and decreasing.

Third, one could build higher dikes. This runs against the trend of ecologicalization, and is counter to the recently adopted government policy of no more dike reinforcement. Dikes are considered ugly and spoil the landscape. Dikes are also expensive, particularly if done properly. A lot of river dikes were built and rebuilt over the centuries. It is seldom known what they were made of, and thus they are difficult to reengineer.[4] Furthermore, there is always a residual risk of dike failure, particularly in the light of the uncertainty about climate change projections. Floods in the densely populated areas of Brabant and South Holland or the petrochemical industry near Rotterdam would be extremely expensive. Therefore, it would be better to relocate flood risks, which is hard to achieve with additional dike building.

Fourth, one could increase the discharge capacity of all three branches by deepening and widening the riverbed. However, getting the water as quickly as possible to the North Sea would cause other problems. Increasing discharge capacity would reduce water flows in summer, which, particularly if combined with higher temperatures, would enhance the probability of droughts, hurting nature, recreation, agriculture, drinking water resources, and navigation. The current, already elaborate system of sluices would need to be substantially and expensively extended to prevent this. Reliable and speedy navigation is important for Rotterdam Harbor, competing as it does with Antwerp and Hamburg. Standards for navigability of the Rhine are laid down in a treaty between the Netherlands and Germany.(3)

Fifth, one could dig a fourth branch. This would be expensive and risky, since such a branch would need to run against natural geography and would require land already used for other purposes.(4) This branch would inevitably flow through *'t Gooi*, which is hilly and populated by well-to-do and well-connected people.

Sixth, one could introduce a bypass. A bypass is a river branch that only occasionally discharges water. A report by Delft Hydraulics(4) opts for this idea. Fig. 1 shows the consequences. If the discharge of the Rhine at Lobith is less than 15,000 m^3/s, everything remains as it is now. All water in excess of 15,000 m^3/s is discharged northward, through the countryside of the province of Gelderland and Overijssel, and later joined with the IJssel to mouth in the IJssel Lake, from where the water would need to be discharged or pumped into the Waddensea. The bypass plan contains two more features. The Waal is turned into a canal, so that navigation is improved. The Lek is turned into a nature reserve.

The bypass as advocated by Delft Hydraulics is obviously not the only option, and probably not the best one.[9] It is the most detailed proposal, however, and clearly demonstrates the scale of intervention that is required to durably manage river flood risks in the Netherlands. In the next section, we review the institutional implications of intervention at this scale.

4. INSTITUTIONAL RESPONSE

The implications of the bypass plan for the provinces of Gelderland and Overijssel are quite drastic. Fig. 2 compares the current and the proposed situation. Large stretches of land would need to be set aside for the newly created bypass. Isolated houses and hamlets would need to go, and some villages and towns would need to be protected by circular dikes. The occasional flooding would be detrimental for agriculture, so that nature development would be the alternative, perhaps combined with estates. The bypass is designed so as to minimize such impacts, but they are still large.

Fig. 2. The proposed bypass and restructured IJssel River. The light areas are currently flood-safe, but will occasionally flood in the proposed situation.(4)

Placed in the context of *democratization*, it is unclear whether the bypass or a similar plan will succeed. Locals would be asked to leave house and hearth for a questionable cause. In a series of interviews we conducted in the area,(6) one of interviewees remarked "Climate change? Ha! One professor says it gets wetter, the other says it gets drier." The fact is that the current decision-making process gives considerable weight to "not in my polder" feelings. The results of the series of interviews suggest that farmers may be willing to move, provided that financial compensation is adequate. However, they would regret the breakup of social life. Recent migrants to the region particularly appreciate the current, open landscape,

[9] See Reference 36 for tools to evaluate adaptation to climate change in the water-resources sector. Yohe and Tol(38) develop their own method and, applying it to the case of the Rhine, conclude that dike reinforcement is the most likely adaptation option.

and thus oppose new dikes and other infrastructure. Both groups, however, would be willing to accept individual losses for the greater good, provided that social benefits are clear to them. On the other hand, these people could and would resist government plans if the necessity is unclear, compensation inadequate, or if something goes wrong in the communication process. This group of people is well organized, and effectively influenced the planning of the *Betuwelijn* (a major new railroad) and dike reinforcements in the same area.[3]

Another issue is that the people of Gelderland and Overijssel would be asked to bear most of the costs (that is, increased flood risks), whereas the benefits (reduced floods risks) would largely befall the people of Brabant and Holland. Over the years, Dutch flood management has consistently upheld the principle of spatially equalized flood risks.[37] Similar regional sentiments, particularly tensions between center (i.e., Holland and Utrecht) and periphery (the rest of the country), have played a role in the management of the Limburg Meuse. People in Limburg subsidize flood management in the west of the Netherlands, while flood risks are substantially higher in Limburg. This is one of the reasons why the central government currently seeks to reduce flood risks in Limburg. Similar arguments may lead to political problems for the bypass plan for the Rhine River.

The Delft Hydraulics plan is not inconsistent with the trend of *ecologicalization*, particularly because the Waal does not need higher dikes and the Lek is turned into a nature reserve. The actual bypass requires engineering, though, and new dikes are needed to protect the towns and villages of Gelderland and Overijssel. As mentioned above, the plan disregards upstream solutions in Germany, ignoring the trend of *internationalization*.

The plan requires *integration* to be taken two steps further. Most importantly, water management and land-use planning need to be interwoven. At the moment, the relevant authorities merely talk to one another, and only occasionally listen. A recent example is the *Betuwelijn*, the planned location of which gets in the way of flood safety reinforcements.

The difficulties in getting different authorities and other stakeholders to agree on policies and actions that address problems overarching specific interests are recognized. New ideas for water management[41] focus on the process of finding feasible approaches to deal with an uncertain future rather than on attempting to find support for a preengineered solution to a predefined problem. The initiative of Delft Hydraulics may be seen as an attempt to start such a process.

Just how hard this is is shown by the *Maaswerken* project. This project aims to improve flood safety along the Meuse. At the same time, it seeks to further commercial mining of sand and gravel and to develop nature. Integration and ecologicalization are thus at work, and so is internationalization since the Meuse cannot be controlled without extensive cooperation with Belgium. In fact, the project includes a slight revision of the international border. The project planning is accompanied by extensive consultation with local and regional stakeholders. The *Maaswerken* project thus combines all elements of possible Rhine projects, although the *Maaswerken* project is smaller, less complex, and less controversial than a restructuring of the Rhine. Nonetheless, the *Maaswerken* project is plagued by troubles.

Ever since its inception in 1990, the project has been overtaken by events, including floods along the Meuse (in 1993 and twice in 1995) and the Rhine (1995), new regulations from The Hague (on flood management, spatial planning, and nature conservation), and new initiatives from Brussels (on international flood management, on water management, and on nature conservation). Initially envisaged as three separate projects, the *Maaswerken* project grew more complex over time. Priorities were revisited time and again—on average, once every year; the emphases shifted from gravel exploitation, to nature conservation, to flood safety, and back—in every possible sequence. The budget was often revised too, and funding continues to be uncertain. Stakeholders grew impatient and tired of the frequent changes. Initially cooperative locals withdrew support, while gravel companies and property speculators press forward. Van der Grijp and Warner[5] extensively discuss the project.

As discussed above, this project is smaller, simpler, and less controversial than the Rhine bypass project. If implementing the *Maaswerken* is so difficult, how feasible are large-scale interventions in the Rhine?

5. CONCLUSION

Climate change could seriously increase flood risks in the Netherlands. This is recognized by the water-management authorities, which have the technical capacity to keep flood risks at or below current levels. The Netherlands is also rich enough to pay for technical solutions. However, a structural solution—such as the bypass plan sketched above—would require strategic thinking, political courage, individual sacrifice for the greater good, and integration of land-use planning and water management. The current institutional setting is such that a structural solution is likely to give way to incidental solutions. Dutch water management has a long history of partial and short-term solutions. Continuing along this path will entail increasing flood risks as well as suboptimal adaptation.

ACKNOWLEDGMENTS

This paper was presented at the EuroConference on Global Change and Catastrophe Risk Management: Flood Risks in Europe, June 6–9, 1999, IIASA, Laxenburg, Austria; at the Stanford EMF Workshop on Climate Change Impacts and Integrated Assessment, July 26–August 3, 1999, Snowmass, CO, USA; at the SIRCH Meeting, March 10–12, 2000, Universidad Politecnica de Madrid, Spain; at the Costing Canadian Climate Change Impacts and Adaptations Collaborative Workshop, September 27–29, 2000, University of British Columbia, Vancouver, BC, Canada; and at the annual meeting of the German Oceanography Society, October 6, 2000, Max Planck Institute for Marine Microbiology, Bremen, Germany. Comments by participants at those workshops helped improve the exposition. Two anonymous referees gave further helpful comments. The research was done in the context of the SIRCH (social and institutional responses to climate change) project. Financial support by the Environment and Climate Programme of CEC-DG12, the U.S. National Science Foundation through the Center for Integrated Study of the Human Dimensions of Global Change (SBR-9521914), and the Michael Otto Foundation is gratefully acknowledged.

REFERENCES

1. Smit, B., Pilifosova, O., Burton, I., Challenger, B., Huq, S., Klein, R. J. T., & Yohe, G. (2001). Adaptation to climate change in the context of sustainable development and equity. Oxford: Oxford University Press. In J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken, & K. S. White (Eds.), *Climate change 2001: Impacts, adaptation and vulnerability—Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 877–912).
2. Tol, R. S. J., Fankhauser, S., & Smith, J. B. (1998). The scope for adaptation to climate change. What can we learn from the impact literature? *Global Environmental Change*, *8*(2), 109–123.
3. van der Grijp, N. M., & Olsthoorn, A. A. (2001). Institutional framework for the management of the rivers Rhine and Meuse in the Netherlands. An overview. In A. A. Olsthoorn & R. S. J. Tol (Eds.), *Floods, flood management and climate change in the Netherlands* (pp. 5–41). Amsterdam: Institute for Environmental Studies, Vrije Universiteit.
4. Delft Hydraulics. (1998). *De rijn op termijn*. Delft: Delft Hydraulics.
5. van der Grijp, N. M., & Warner, J. (2001). Planning and decision-making related to the Maaswerken project. In A. A. Olsthoorn & R. S. J. Tol (Eds.), *Floods, flood management and climate change in the Netherlands* (pp. 67–88). Amsterdam: Institute for Environmental Studies, Vrije Universiteit.
6. van der Werff, P. E. (2001). Nature or neighbour in hell's angle: Stakeholder responses to future flood management plans for the Rhine river basin. In A. A. Olsthoorn & R. S. J. Tol, (Eds.), *Floods, flood management and climate change in the Netherlands* (pp. 89–116). Amsterdam: Institute for Environmental Studies, Vrije Universiteit.
7. Miller, K. A., Rhodes, S. L., & MacDonnell, L. J. (1997). Water allocation in a changing climate: Institutions and adaptation. *Climatic Change*, *35*, 157–177.
8. Cohen, S. J., Miller, K. A., Hamlet, A. F., & Avis, W. (2000). Climate change and resource management in the Columbia River basin. *Water International*, *25*(2), 253–272.
9. Kelly, P. M., & Adger, W. N. (2000). Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change*, *47*, 325–352.
10. Strzepek, K. M., Yates, D. N., Yohe, G. W., Tol, R. S. J., & Mader, N. (Forthcoming). Constructing "not implausible" climate and economic scenarios for Egypt. *Integrated Assessment*.
11. van den Berg, J. T., & van Hall, A. (1997). *Waterstaats- en Waterschapsrecht*. Deventer: W.E.J. Tjeenk Willink.
12. van Hall, A. (1997). *Waterbeheerswetgeving*. Lelystad: Koninklijke Vermande.
13. Mostert, E. (1997). *Water policy formulation in the Netherlands* (RBA Series on River Basin Administration 6). Delft: Delft University of Technology.
14. Perdok, P. J. (1995). *Institutional framework for water management in the Netherlands* (RBA Series on River Basin Administration 3). Delft: Delft University of Technology.
15. Langen, A., & Tol, R. S. J. (1998). A concise history of riverine floods and flood management in the Dutch Rhine delta. In T. E. Downing, A. A. Olsthoorn, & R. S. J. Tol (Eds.), *Climate change and risk* (pp. 162–172). London: Routledge.
16. Langen, A., & Tol, R. S. J. (Forthcoming). A concise history of Dutch river floods. *Climatic Change*.
17. de Villeneuve, C. H. V. (1996). Consistentie, transparantie en subsidiariteit: Naar samenhand in het internationaal waterbeheer? *M en R*, December, 12.
18. Mostert, E. (1998). River basin management in the European Union. *European Water Management*, June/July, 26–35.
19. Gilhuis, P. C., & Menninga, H. (1996). Natuur en milieu in waterschapswet, *M en R*, December, 12.
20. van Hall, A. (1997). Complementair bestuur tussen gemeente en waterschap. *M en R*, *11*(November).
21. Katsburg, P. R. A. (1996). De verkiezing verkozen. *Het Waterschap*, *81*(4), 122–128.
22. Kroon, J. (1997). Voeten blijven droog. *NRC*, May 7.
23. Hisschemoller, M. (1985). Afzien van Afsluiten: De dienst rijkswaterstaat in de jaren zeventig. In H. A. van de Heijden J. Kastelein, & J. Kooiman (Eds.), *Succes- en Faalfactoren bij Bestuurlijke Reorganisaties*. Groningen: Wolters-Noordhoff.
24. Brignall, A. P., Downing, T. E., Favis-Mortlock, D. T., Harrison, P. A., & Orr, J. L. (1998). Agricultural drought in Europe: Site, regional and national effects of climate change. In T. E. Downing, A. A. Olsthoorn, & R. S. J. Tol (Eds.), *Climate, change and risk* (pp. 79–124). London: Routledge.
25. Gruebler, A. (1998). A review of global and regional sulfur emission scenarios. *Mitigation and Adaptation Strategies for Global Change*, *3*(2–4), 383–418.

26. Kwadijk, J., & Middelkoop, H. (1994). Estimation of impact of climate change on the peak discharge probability of the River Rhine. *Climatic Change*, *27*, 199–224.
27. Parmet, B., & Raak, M. (1995). *Impact of climate change on the discharge of the River Rhine* (RIVM-410100069). Bilthoven: RIVM.
28. Middelkoop, H., Daamen, K., Gellens, D. *et al.* (2001). Impact of climate change on hydrological regimes and water resources management in the Rhine basin. *Climatic Change*, *49*, 105–128.
29. Penning-Rowsell, E. C., & Fordham, M. (1994). *Floods across Europe, flood hazard assessment, modelling and management*. London: Middlesex University Press.
30. Reynard, N. S., Prudhomme, C., & Crooks, S. M. (2001). The flood characteristics of large U.K. rivers: Potential effects of changing climate and land use. *Climatic Change*, *48*, 343–359.
31. Commissie Watersnood Maas. (1994). *De maas terug!* Delft: Delft Hydraulics.
32. van den Berg, J. T., & van Hall, A. (1997). *Waterstaats- en Waterschapsrecht*. Deventer: W.E.J. Tjeenk Willink.
33. Schuurman, A. (1995). *An insurance for the Meuse* (W95/19). Amsterdam: Institute for Environmental Studies, Vrije Universiteit (in Dutch).
34. Handmer J., Penning-Rowsell, E., & Tapsell, S. (1998). Flooding in a warmer world: The view from Europe. In T. E. Downing, A. A. Olsthoorn, & R. S. J. Tol (Eds.), *Climate, change and risk* (pp. 125–161). London: Routledge.
35. Riebsame, W. E., Strzepek, K. M., Wescoat, J. L., Perritt Jr., R., Gaile, G. L., Jacobs, J., Leichenko, R., Magadza, C., Phien, H., Urbiztondo, B. J., Restrepo, R., Rose, W. R., Saleh, M., Ti, L. H., Tucci, C., & Yates, D. N. (1995). Complex river basins. In K. M. Strzepek & J. B. Smith (Eds.), *As climate changes—International impacts and implications* (pp. 57–91). Cambridge: Cambridge University Press.
36. Tol, R. S. J. (1998). Climate change and insurance: A critical appraisal. *Energy Policy*, *26*(3), 257–262.
37. Yohe, G. W., & Tol, R. S. J. (Forthcoming). Indicators for social and economic coping capacity—Moving towards a working definition of adaptive capacity. *Global Environmental Change*.
38. Olsthoorn, A. A. (2001). The evolution of acceptable risk. In A. A. Olsthoorn & R. S. J. Tol (Eds.), *Floods, flood management and climate change in the Netherlands* (pp. 43–58). Amsterdam: Institute for Environmental Studies, Vrije Universiteit.
39. Kraemer, W. (1999). Personal communication. Berlin.
40. van Schoubroeck, C. (1997). Legislation and practice concerning natural disasters and insurance in a number of European countries. *Geneva Papers of Risk and Insurance*, *22*(83), 238–267.
41. van Schoubroeck, C. (1997). Legislation and practice concerning natural disasters and insurance in a number of European countries. *Geneva Papers of Risk and Insurance*, *22*(83), 238–267.